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Impulse Drying: Status of the Pilot-Scale Research Program

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IMPULSE DRYING: STATUS OF THE PILOT-SCALE RESEARCH PROGRAM

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ABSTRACT

The Institute of Paper Science and Technology and the Beloit Corporation have a joint project to develop impulse drying for application to board grades. The objectives of the project are to develop the necessary technology and to demonstrate that technology on a pilot paper machine.

Over the past few years much progress has been made toward solving the sheet delamination problem, which had previously been the major stumbling block to the commercialization of impulse drying for board grades of paper. These solutions, which have been demonstrated in laboratory experiments, have now been demonstrated during continuous operation on a pilot paper machine.

This paper describes the process modifications that have allowed impulse drying of board grades to become commercially feasible, discusses the methodologies that were used in developing commercial prototypes, and reports the results of pilot paper-machine experiments where these prototypes have been utilized. In addition, the current status of the commercialization is discussed, as are potential new applications of the technology.

BACKGROUND

In the watershed paper by Crouse, Woo and Sprague [1], impulse drying was shown to have the potential of disrupting and delaminating (breaking of fiber bonds) the linerboard sheet. They found that delamination could only be avoided when the sheet-fed pilot press was operated at temperatures below 150°C. Conditions that only resulted in sheet strength and press dryness that could as easily be achieved by conventional pressing at elevated ingoing sheet temperatures. Hence, it was concluded that delamination must be fully understood and be alleviated for impulse drying to become a commercial technology that is applicable to the manufacture of board grades.

In response to the work of Crouse, Woo and Sprague, research was undertaken at a number of corporate and academic research centers to overcome the sheet delamination problem. Early work focused on identifying significant variables and developing causal hypotheses. In work reported by Burkhead, Burns, Lindsay, and Orloff [2], delamination was found to be affected by the felt initial moisture content. The use of bone-dry felt resulted in poorer dewatering and was more likely to cause delamination than were slightly moist felts. It was speculated that the effect of initial felt moisture might be due to observed differences in the dynamic compression behavior of the felt or to changes in its water absorption properties. Although felt moisture played a role in delamination, press surface temperature, peak mechanical pressure, and nip residence time were also identified as important process variables.

Back [3] reported that the risk of delaminating the wet sheet when it exits the nip had been underestimated by previous investigators. He reasoned that this had occurred, on the one hand, through the use of residence periods in the press nip which cannot yet be realized at modern machine speeds, and, on the other hand, as a result of the relatively long periods required to relieve pressure in pilot tests. In a paper on hot pressing, Back [4] examined the limitations of impulse drying. He recommended further research that focuses on improving z-direction strength and suggested that the economics of impulse drying could be improved by the use of equipment that permits an extended residence time in the nip and a slow reduction in pressure. In a later review article, Back [5] set forth what he considered as requirements for impulse drying equipment. These included using the longest possible dwell time to achieve maximum outgoing solids and z-directional wet strength; a low pressure deloading rate to reduce drag forces, which cause delamination; and a low outgoing maximum temperature in the wet web, especially where most moist. Hence, Back saw the solution to delamination as being associated with the temporal change in pressure experienced by the sheet within the nip and minimization of heat transfer to the sheet during nip opening.

From this starting point, research on preventing delamination took two separate paths. The first path consisted of modifications to the press nip such as reducing the thermal properties of the press roll, drilling the press roll, and changing the conditions of the nip, for example, impulse, pressure profile, and sheet construction. The second path, which has been much more sparsely reported in the literature, approaches the problem through modifications to the conditions the sheet experiences after it leaves the nip. Examples that will be discussed include the use of steam chambers, gas chambers, roll wraps, and secondary nips.

Modifications Within the Nip

To prevent delamination, Stenstrom [6, 7] proposed the use of a press surface that would make it possible to evacuate vapor from the hot surface of the sheet through a number of radial drilled holes. He reasoned that, while in the nip, the hydraulic pressure prevents vaporization during most of the contact time. However, the sudden pressure decrease, when leaving the nip, causes vaporization and rapid flow of water vapor out of the sheet. If the z-direction wet strength of the web in this moment is not high enough to withstand the internal vapor pressure, the web will break and delaminate in two or more layers. He concluded that in order to prevent high vapor pressures, vapor flow and vaporization should also be made possible during contact in the nip. As resistance to vapor flow is lower in the dried, as compared to the wet part of the sheet, vapor flow can be achieved by venting the hot surface in contact with the sheet. Using similar reasoning, Pulkowski [8] patented a porous press roll surface for use in impulse drying.

Approaching the problem from the heat transfer standpoint, Kloth, Orloff, and Rudemiller [9] patented a low thermal diffusivity press roll surface. Subsequent patents issued to Lenling and Orloff [10] and Orloff [11] further developed the use of insulating press roll surfaces for the purpose of reducing the likelihood of sheet delamination.

In a paper by Orloff [12], the development, design concept, and performance properties of a prototype insulating roll-coating material that could extend the operating temperature of impulse drying were described. Impulse drying simulations, at short dwell times and ingoing sheet temperatures that were consistent with current practice, were reported. It was found that reducing the effective "thermal mass" of the heated press surface and increasing peak operating pressure allowed operating temperatures to be increased. Under these conditions, impulse drying was used to achieve higher outgoing solids, higher final sheet densities, and higher specific elastic modulus without sheet delamination.

Using the insulated press roll surface technology, Orloff and Sobczynski [13] report additional process modifications that facilitate the drying of heavyweight grades while avoiding sheet delamination. The research examined the influence of specific surface, assessed the relationship between specific surface and energy transfer, and presented an estimate of anticipated energy savings. Two virgin-fiber Kraft furnishes of southern pine *(Pinus)* were impulse dried on a pilot roll press featuring a plasma-sprayed ceramic-coated roll. The out-of-plane permeability of the sheets was measured as a function of sheet porosity to determine the hydrodynamic specific surface of each sheet. The results showed that specific surface limited the maximum impulse-drying temperature. Data from laboratory simulations suggested that the use of the ceramic coatings avoided sheet delamination by decoupling heat transfer from overload pressure and the physical state of the sheet.

Lindsay and Orloff [14] investigated the influence of yield, refining, and ingoing solids on the impulse drying performance of the ceramic-coated press roll. Furnishes of southern pine *(Pinus)* were used in pilot-scale impulse drying experiments that covered a range of refining levels, ingoing solids, and kappa numbers. These experiments produced sheets with a range of hydrodynamic specific surfaces. The results confirmed earlier laboratory findings that indicated that the roll temperature at which sheet delamination initially occurs was a function of the specific surface of the ingoing web, which was, in turn, a function of cooking, refining, and pressing variables.

To extend the work to more typical linerboard sheet structures, simulations of the impulse drying of recycled multi-ply linerboard were carried out by Orloff [15]. The experiments were conducted to determine the influence of several factors on impulse-drying performance. These factors included virgin pulpwood species, OCC content, and composition and freeness of the individual plies in two-ply linerboard. Virgin pulp species was found to be important because southern pine *(Pinus)* was found to be superior to Douglas-fir *(Pseudotsuga menziesii)*. Single-ply blends composed of 50% or less OCC had better strength, and those with 75% or less OCC content had better dryness. For two-ply linerboard constructed of blended bottom sheets and virgin-fiber top sheets, the composition of the sheet contacting the heated press surface controlled the critical temperature of impulse drying (i.e., the highest temperature that could be used to impulse-dry the sheet without causing delamination).

In another simulation, Boerner and Orloff [16] explored the effect of basis weight and refining on sheet permeability and critical impulse-drying temperature. Linerboard grades with basis weights of up to 400 g/m^2 and freeness of 600 ml CSF could be impulse-dried without delamination when a heated press surface with a low "thermal-mass" coating was used. Permeability measurements showed that the critical impulse-drying temperature could be predicted from the hydrodynamic specific surface of the sheet. The reason that Darcian permeability was greater in lightweight sheets may be due to the presence of nonuniformities (macropores) that extend through the sheet thickness and allow fluids to pass through. In contrast, in sheets with a higher basis weight, the macropores did not extend through the sheet, so that porosity was controlled by the hydrodynamic specific surface of the fines and fibers in the sheet. Comparisons of outgoing sheet dryness and compression strength with sheets pressed in a double-felted Extended Nip^R press showed that impulse drying was better.

Orloff and Phelan [17] studied the influence of pressure profile on impulse drying. In these simulations, pressure pulse shape was varied while heat flux, critical temperature, and the development of paper physical properties were measured. It was found that the pressure peak should be maximized and should be shifted to the dry end of the process to optimize water removal and sheet strength. Hence, besides providing the long residence time beneficial to impulse drying, a shoe press also provides the optimum pressure pulse shape.

To demonstrate the usefulness of these process modifications, Crouse, Orloff, and Phelan [18] conducted experiments in which linerboard was impulse dried on a sheet-fed pilot shoe press which was fitted with a press roll having a low "thermal mass" coating. For a wide range of one- and two-ply linerboard sheet structures, impulse-drying and double-felted pressing were compared. Performance indicators included STFI compression strength, press dryness, and flexographic printability. The results confirmed simulations [15] that showed impulse drying to be superior to double-felted pressing.

To provide insight into the reasons why low "thermal mass" press surfaces are useful, Kerschner, Orloff, and Phelan [19] performed experiments to test the hypothesis that excessive energy transfer to the sheet, by itself, accounts for sheet delamination. Steel- and ceramic-coated platens were used in simulations that investigated the effect of thermal mass and peak pressure on energy transfer during impulse drying. Shoe-press pressure profiles at three levels of peak pressure, viz., 6.5, 8.5, and 9.5 MPa; two levels of ingoing solids, viz., 36 and 47%; and two furnishes with hydrodynamic specific surfaces of 1.4 and 10.5 m^2/g were simulated. The press surfaces were equipped with vacuum-deposited surface thermocouples. Temperature profiles measured during the impulse-drying event were used to calculate heat flux to the sheets. The results showed that, for a given sheet structure, there was no unique critical energy that was required to initiate sheet delamination. For the ceramic surface, the energy transferred to the sheet was dependent on temperature but not on pressure. In contrast, the energy transfer from the steel surface was dependent on both temperature and pressure. Compared to the ceramic case, there was a substantial amount of scatter in the steel energy data, indicating that local variations in paper properties (e.g., moisture content) and nip pressure may influence total energy transfer for the steel surface. These results partly explain why low "thermal mass" press surfaces are useful and also pointed out that further improvements to impulse drying technology would need to come from post-nip modifications.

Modifications After the Nip

In an early paper by Miller [20], "multipulse" drying units were compared with impulse dryers. He described the "multipulse" machine as consisting of a heated, free-floating drum between two movable nip rolls that tension a belt around the drum and the rolls. He reports that multiple nips are more effective than a single nip, and that they lessen web shrinkage, enhance heat transfer, and inhibit sheet delamination. He explains the delamination inhibition of the "multipulse" units by noting the differences between the impulse cycle and the "multipulse" cycle. The "multipulse" nips are shorter, putting less energy into the sheet at each nip. As a result, less energy internal to the sheet vents as vapor. In the case of the first "multipulse" nip and the interior nips, the sheet is constrained on the exit of the nip so the internal vapor expands only to the intermediate pressure level and is constrained while doing so, typically at 170 to 240 kPa (10 to 20 psig). The last nip is therefore the critical one, and it has two benefits over the impulse nip. It inputs less energy to the sheet and it is operated at a higher ingoing solids. Hence, Miller viewed the solution to the delamination problem as requiring multiple short residence time roll nips with the sheet being constrained between these nips. A few years later, Crouse [21] patented the concept of using two successive Extended Nip^{R} presses with two separate heated press rolls configured such that the web is held in contact with the press rolls both before and after entering into the press nips by felt.

Babinsky and Mumford [22] assumed that delamination occurred during or immediately after the sheet exits the nip. They hypothesized that they could eliminate delamination by reducing the rate of vaporization from the sheet as it leaves the press nip. To reduce the rate of vaporization, they proposed exposing the exiting sheet to a steam environment. In their patent they use a steaming chamber positioned just downstream from the nip. The steam chamber was sealed against the press rolls and required a downstream exit seal through which the web can pass. Steam was injected into the chamber to keep the chamber pressure at about 200 kPa (2 atmospheres). Means were also provided to preheat the web upstream from the nip. These arrangements permitted the reduction of the temperature of the heated roll and reduced the magnitude of the pressure changes to which the web was subjected, thus reducing the chance of delamination.

Recognizing that further improvement to impulse drying technology would need to come from modifications after the nip, Orloff [23] proposed modifications to the impulse drying simulator to allow process modifications during and immediately following nip opening. Orloff hypothesized that delamination occurs when subcooled water, at high pressure and temperature in the sheet, flashes to vapor when the nip opens to ambient pressure. To test the significance of the pressure that the sheet is exposed to upon nip opening, Orloff designed the simulator so that at nip opening the sheet would be exposed to pressures well above one atmosphere. If the hypothesis was correct, then sheet delamination would be eliminated.

Using the modified simulator, Orloff [24] patented a method of impulse drying at elevated ambient nip-opening pressures. The method exposes the web to ambient pressures above atmospheric and provides for increasing cooling rates when the press load is released. The patent teaches that sheet delamination can be prevented by opening the nip to a sufficiently high "critical" ambient gas pressure. The gas used can be any gas as long as it is at a temperature below 100°C. Based on simulations, "critical" pressures were found to increase with increased temperature of the heated press surface, increased basis weight, increased ingoing sheet moisture content, and increased specific surface of the sheet.

In recent research, thermocouples imbedded in sheets have been used to record internal temperature profiles during nip opening. Using thermodynamic reasoning, it showed under what conditions those temperatures could be used to infer local pressures. In this manner it was possible to show that opening the nip to higher ambient gas pressures actually reduced the pressure difference between the inside and outside of the sheet during that critical time [25-27]. Thus the sheet is held together while the internal pressure decays. While it is possible to hold the sheet together with an external gas pressure, a simpler way would be to provide an external mechanical force. Based on this reasoning, IPST filed a US patent [28] to cover the application of elevated pressures by such techniques as post-nip roll wraps and post-nip shoes. To demonstrate that this concept is not just a laboratory curiosity, the concept was implemented on Beloit's No. 2 and No. 4 pilot paper machines.

CHRONOLOGY OF PILOT RESEARCH

Following an agreement between IPST and Beloit on July 31, 1995, an induction heating system and special inductors were designed and installed on the third press of the Beloit X4 pilot paper machine. This converted the existing single-felted extended nip press to an impulse dryer. The Impulse Dryer was started in December 1996.

January 1997

The Beloit X4 pilot paper machine was started up in a single-felted wet pressing mode to verify that 205 gsm linerboard could be produced at machine speeds of 380 m/min. The machine has a vertical twin-wire forming section, while the press section was configured with a Bi-nip roll press followed by a 0.25 m-long shoe press (ENP). The Bi-nip was set at a press loading of 70 kN/m on the first press and 105 kN/m on the second press. The ENP was configured with a post-nip roll wrap and set at 1050 kN/m. The press roll of the ENP was coated with Beloit "E" coating, while an Albany International "CSX" press felt was used. Employing a once-dried Kraft (composed of mixed softwood, hardwood, and OCC) repulped to a freeness of 670 ml CSF, press dryness of between 48 to 50% was achieved at a basis weight of 209 gsm. Samples from the reel were tested yielding an average caliper of 346 μm and an average apparent density of 0.605 g/cm^3.

The ENP roll on the Beloit X4 pilot paper machine was heated to 163°C and an attempt was made to thread a paper web through the press section. The roll cover failed; therefore, the trial had to be aborted. Observations indicated the cover was too thick to withstand the high temperatures. Co-current roll coating durability testing at IPST had shown that a coating of similar composition (but reduced thickness) had been exposed to nearly 5 million thermal and mechanical cycles without failure. Based on these results, and a comparison of the coating thickness on the ENP roll and the IPST roll, it was decided to go ahead with March X4 experiments with a roll coated with a thinner coating of Beloit "E."

Low-speed heated roll press extended nip simulation experiments, performed at Beloit, suggested that a post-nip roll wrap does help to inhibit sheet delamination during impulse drying.

February 1997

An investigation was begun on what mechanisms could cause such a failure. To confirm IPST roll durability results, the IPST press roll on the roll durability test facility was thoroughly cleaned and the coating was examined under 30X magnification. Under this magnification, defects on the order of 5-10 mm in width, which were typical crack widths observed on the failed X4 roll, would be apparent. The examination did not reveal cracking.

March 1997

Experiments continued on the Beloit X4 machine. The thinner roll coating survived, felt performed above expectations, and threading was accomplished at high temperature. Linerboard, at a basis weight of 205 gsm, was produced at speeds of 380 to 457 m/min. No roll coating cracking or spalling was noted after two weeks of operation at speed, load, and temperature. The CSX felt operated to 260°C, at a speed of 457 m/min, and a press load of 1050 kN/m. The machine could be threaded at a roll temperature of 204°C.

The control of CD roll surface temperature specifically during initial roll heating, threading, and steady state operation is important and required additional development. Sheet picking was observed at higher roll temperatures than were previously observed on Beloit's heated roll press and IPST's MTS. This made CD roll surface control critical during attempts to set the roll temperature between the sticking temperature and the critical impulse drying temperature. The available post-nip felt wrap yielded a pressure of 20 kPa, which was insufficient to prevent sheet delamination even for high freeness. As a result, the picking temperature was higher than expected and the critical temperature was lower than expected, resulting in a nonexistent operating window. It was observed during the trial that the special TET blocks holding thermocouples to the heated roll surface yielded MD streaks in the web where there was no picking while adjacent areas of the sheet showed picking. This suggested two courses of action: either include the special material in the blocks in the roll surface coating or apply it continuously, with a special doctor blade, during normal roll operation.

April 1997

The shakedown work was continued on Beloit's, more readily available, X2 pilot paper machine. The X2 was fitted with the first pilot machine Impulse Dryer in 1987. In order to address the sticking problem, Beloit initiated development of a new roll coating, Beloit G. IPST and Beloit also worked on a decompression ramp shoe to address the delamination problem.

May 1997

A laboratory investigation to determine a range of ramp profiles, which are both physically possible on a shoe press and which provide a reasonable increase in critical temperature, was performed at IPST. The simulations used the same furnish as was used during the March '97 X4 trial and was performed on the MTS hydraulic press. Using the IPST data, Beloit began building the new shoe, which incorporated a ramp on the end of a shortened ENP shoe. The design allowed for the start pressure and duration of the ramp to be adjustable mechanically when the shoe was taken out of the machine.

Additional roll durability testing brought the IPST press roll, with the four coatings, to approximately 10 million thermal/mechanical cycles. The roll was cleaned and examined under 100X magnification. There were no cracks observed.

June 1997

The furnish used in March '97 was run on the X2 machine equipped with the new Beloit "G" press roll coating. The shoe used was a standard 0.25-m shoe with no ramp. The intent of this trial was solely to investigate sticking. The new roll coating was successful in preventing sticking at roll temperatures of 180 to 210°C.

July 1997

An X2 machine trial took place using a once-dried Virgin softwood Kraft furnish at 550 ml CSF, 30% ingoing solids, and at a machine speed of 380 m/min. Sheet weight was limited to 100 gsm. The purpose was to evaluate recent shoe modifications and determine an optimized ramp. The shoe evaluated was a 0.15-m-long shoe with an 0.20-m extension designed to produce a ramp at the end of the main profile. The extension was adjustable when taken out of the machine. This allowed limited but time-consuming modification of the ramp characteristics. This preliminary work showed the ramp could be used to increase the critical temperature by 20 to 40°C.

August 1997

Another X2 machine trial took place using the same once-dried Kraft, at 550 ml CSF, at an ingoing solids of 30%, 100 gsm, and at a continuous machine speed of 380 m/min. The purpose was to continue the work begun during the July X2 trial, specifically optimization of the trailing ramp portion of the pressure pulse. During the trial a profile was found which made it possible to impulse dry the sheet with a roll temperature in excess of 207°C. It was also shown that by applying a TET doctor blade to the heated roll surface, with sufficient pressure, picking can be significantly reduced. Physical testing of samples showed a 55°C increase in critical temperature, and a 6% increase in dryness, and up to a 20% increase in STFI compression strength.

The shoe used in the trial had the disadvantages of requiring that it be removed from the ENP in order for the ramp profile to be adjusted and that the short shoe resulted in peak loads that induced picking. To rectify these shortcomings, the design of a standard 10-inch shoe with two modifications was initiated. One was a more "user friendly" shoe that could also be used on the X4 machine. The other was a mechanism for applying air pressure to the web just as it exits the nip. The later mechanism would apply air pressure (~200 kPa max.) over an area the full CD width of the machine and about 0.10 to 0.18 m in the MD direction. It can best be thought of as a stationary hover craft. A preliminary version of the device was tested on Beloit's heated roll press using large hand sheets.

September 1997

Preliminary tests of a prototype "hover press" on Beloit's slow-speed heated roll press indicated that there was no decrease in outgoing solids resulting from the applied air pressure. Additionally, the process modification appeared to inhibit delamination.

October 1997

It was agreed to use a standard 0.25-m shoe with a 0.10-m ramp extension as well as a "hover press" in subsequent experiments. Beloit designed the ramp extension so that the applied pressure, and the resultant ramp profile could be adjusted while the machine was running. This provided a significant advantage over the previous design. The "hover press" was designed with chambers allowing for progressive decreases in applied air pressure as distance from the nip exit increases. The peak applied air pressure was 200 kPa gage. IPST arranged to have a large capacity air compressor available for the test to supply air to the "hover press."

January 1998

Impulse drying experiments were conducted on the Beloit X2 pilot paper machine. A full week of experiments were conducted in which internal ramp and external hover press combinations were evaluated for a range of freeness and over a range of machine speeds. In addition, two blanket drainage geometry's were also investigated.

PILOT PAPER-MACHINE EXPERIMENTS

This section will review experiments performed in the Summer of 1997 and the Winter of 1998.

The Summer Experiments

The purpose of the experiments was to verify that the ramp decompression concept could be used to extend the temperature operating window of high-speed continuous impulse drying and that sheet/roll surface picking could be eliminated by proper choice of press roll surface and/or by special doctoring technology.

While the X2 machine has certain limitations with regard to basis weight, ingoing solids, and width, it has the advantages of having an induction-heated open-extended-nip press. The open-extended-nip press was desirable as it did not significantly limit press shoe length and geometry. An overall schematic diagram of the X2 machine is shown in Figure 1 and a close-up showing the location of the adjustable ramp shoe and the "hover press" used in the Winter 1998 experiments is shown in Figure 2.

As the shape of the pressure profile generated by the press shoe and the "hover press" were major variables of the experiments, its measurement was important. To this end, a TechScan pressure measurement system was used to both statically and dynamically measure pressure profiles. Typical profiles at a press load of 1050 kN/m used during the Summer 1997 experiments are shown in Figure 3. The "standard" profile corresponds to the pressure distribution resulting from a commercial Beloit 0.25-m shoe. The "Short/Ramp" profile corresponds to the profile obtained from a 0.18-m shoe followed by a 0.18-m adjustable ramp. The specific ramp profiles investigated during the Summer 1997 experiments are shown in Figure 4. Note that the ramps each followed the short shoe, as indicated in Figure 3.

The first objective of the Summer 1997 experiment was to characterize the performance of the standard 0.25-m shoe with and without the use of a steambox just prior to the impulse dryer. Based on zd-specific elastic modulus measurements, the critical impulse drying temperature of the unheated web was about 165°C, while that of the preheated web was less than about 154°C. As web preheating added an extra complication to the experiments and was generally ineffective at low freenesses, it was decided to delete the steam box from future experiments.

The second objective was to determine whether the use of the short shoe with the ramp could be used to increase the critical impulse drying temperature above that obtained using the standard 0.25-m shoe. The short shoe with the ramp was designed so as to generate the same impulse (area under the pressure - time curve) as the standard shoe. These experiments were conducted without the use of the steambox and yielded a critical impulse drying temperature of 204°C. It was concluded that the modified profile resulted in an increase in the window of operation of about 40°C.

Additional, more detailed, experiments were also conducted in the Summer of 1997. In these experiments, attempts were made to adjust the ramp profile shapes to more closely match those of laboratory simulations. The resulting ramps (#4 and #5) were generally of lower pressure than ramp #2 but were still jagged in shape. Table 1 shows the setup conditions of the gap former and the impulse dryer. The furnish used for this as well as the earlier Summer experiments and the later Winter 1998 experiments was a once-dried Virgin unbleached softwood Kraft. For these specific experiments the furnish was repulped and minimally refined to a freeness of 570 ml CSF. The ingoing solids to the impulse dryer was maintained between 31.5 and 32.2% solids while the basis weight was set at a nominal 100 gsm. Permeability testing of the wet web showed that the specific surface was between 3.2 and 4.1 m^2/g, as shown in Table 2. The machine was operated at 380 m/min.

Using the short shoe with ramps #4 and #5, impulse drying experiments were conducted at a press load of 1050 kN/m over a range of press roll surface temperatures between 190 and 250°C. Based on zd-elastic modulus data, the critical impulse drying temperature was about 218°C for ramp #4 and 209°C for ramp #5. Comparing the paper physical properties at the various critical temperatures and to corresponding wet pressing controls, impulse drying yielded a 5-point increase in press dryness, increased sheet smoothness, and Gurley as well as providing improvements in STFI compression strength and ring crush.

In addition to demonstrating the usefulness of modifying the press shoe, the Summer experiments also demonstrated the usefulness of using a heavily loaded special TET doctor to minimize and, under some conditions, eliminate sheet/press roll picking. To further explore the variables influencing picking, a side experiment was conducted at various press loads while maintaining the press roll surface temperature at 204°C. It was found that picking decreased with decreasing peak press load.

The Winter Experiments

There were a number of objectives of the Winter experiments. These included the evaluation of an improved adjustable (on-the-fly) press shoe ramp and the evaluation of an initial version of the "hover press." It was also desirable to determine the effect of refining and machine speed on critical impulse drying temperature and runnability (sheet/press roll surface picking).

The Summer experiments had indicated that picking could be reduced by reducing the peak press load. Hence, the press shoe profile should be designed in such a way so as to minimize the peak pressure while maximizing the impulse. The improved adjustable ramp was designed to follow a standard 0.25-m shoe. To contain the shoe and ramp within the existing open-extended-nip press, the new adjustable ramp length was limited to a length of 0.10 m. Figure 5 shows three press shoe pressure profiles that were investigated during the Winter experiments. The following nomenclature was used:

- Ramp 8 Off - Hover Off: the ramp as well as the "hover press" were installed but not pressurized.
- Ramp 8 On - Hover Off: the ramp was pressurized while the "hover press" was not pressurized.
- Ramp 8 On - Hover On: both the ramp and the "hover press" were pressurized.

The Winter experiments also provided an opportunity to explore whether blanket design would influence impulse drying. To accomplish this, the drive side of the blanket was grooved while the operator side was blind-drilled. Table 1 documents the forming and pressing conditions that were employed.

The same furnish used in the Summer experiments was also used in the Winter experiments. The ingoing solids, hydrodynamic specific surface and freeness of cases investigated are shown in Table 2.

The experiments were conducted over a three-day period. At the start of each day, wet pressing controls were run for each of the three press shoe profiles. Afterwards, the press roll was heated to a range of temperatures and impulse drying samples were taken. The X2 machine was run at a speed of 380 m/min during the first two days and increased to 760 m/min on the third day. To investigate the effect of refining, the furnish was refined to 540 ml CSF on the first day and 460 ml CSF on the second and third days.

As in previous studies, the drop off of the zd-specific elastic modulus was used as the indicator of the critical impulse drying temperature. It was observed that the grooved blanket consistently resulted in a higher modulus than did the blind-drilled blanket. This suggested that nip venting may be a more important factor in impulse drying than had been previously realized. It also suggested that the blanket groove geometry should be optimized. The critical temperatures were determined and outgoing solids and paper physical properties were reported at these conditions.

DISCUSSION

Table 3 summarizes the impulse drying critical temperatures that were determined in the pilot experiments that were conducted in the Summer of 1997 and the Winter of 1998. A few differences are particularly interesting. It is noted that the critical impulse drying temperature of the Summer 1997 standard 0.25-m shoe (with no ramp) was about 21°C lower than the critical impulse drying temperature for the Winter 1998 standard 0.25-m shoe with Ramp #8 and the "hover press" both being unpressurized. There are a number of factors that contribute to these differences. There are differences in ingoing solids, freeness (and hydrodynamic specific surface), and small differences in the pressure profiles. Based on previous laboratory simulations, it was expected that a decrease in ingoing solids would decrease the critical impulse drying temperature. Likewise, an increase in hydrodynamic specific surface and a corresponding decrease in freeness would also result in a decrease in critical impulse drying temperature. As these trends were not observed, the differences in pressure profile were considered. Referring to Figure 3, the standard 0.25-m shoe pressure dropped the last 690 kPa in less than 0.025 m. Referring to Figure 24, the standard 0.25-m shoe with the unpressurized Ramp and hover dropped the last 690 kPa in just over 0.05 m. Hence, the unpressurized Ramp and hover profiles would be expected to result in some reduction in the net pressure difference between the inside and outside of the web as it leaves the impulse dryer. This effect could have resulted in the observed increase in critical impulse drying temperature. As the ingoing temperatures for all cases were about the same (40°C), the pressure profile was most probably the cause of the observed difference. Hence, an attempt to impulse dry the Winter 1998 furnishes with a standard 0.25-m shoe, would have produced an even lower critical temperature than was observed in Summer 1997.

The remaining critical impulse drying temperature data appears to be internally consistent. Based on the analysis in the previous paragraph, it was concluded that the 0.1-m-long ramp is probably adequate in length for future experiments on the Beloit X4 pilot paper machine.

In the Winter 1998 experiments, there was a consistent difference between the specific elastic modulus of paper produced with the grooved blanket and the blind-drilled blanket. In almost all cases, paper wet pressed or impulse dried on the grooved side was stronger than that wet pressed or impulse dried on the blind-drilled side. This was interpreted as resulting from higher amounts of rewet or lower press solids on the blind-drilled side which would reduce web densification and strength. This would be consistent with the hypothesis that the blind-drilled blanket did not provide a sufficient path for venting of water from the felt while the paper web and felt are in the nip. With this in mind, physical property development was compared between the various cases based entirely on data from the grooved blanket side of the web. Tables 4 and 5 list the outgoing solids, Bendtsen roughness of the heated side, as well as the CD and GM STFI compression indices for the wet-pressed controls and the impulse-dried samples at the appropriate critical temperatures. It should be noted that samples for outgoing solids measurement were always taken across the entire web. Hence, for the Winter 1998 experiments, the tabulated outgoing solids slightly overstates the outgoing solids for the blind-drilled blanket side of the web and understates the outgoing solids for the grooved blanket side of the web.

Referring to Table 4, attention is focused on the following cases: Short-Ramp 4, Short-Ramp 5, and Std-Ramp 8 On-Hover Off. In these cases, outgoing solids was improved over wet pressing by 4 to 13%. Similarly, surface smoothness improved by 22 to 51%. Examination of Table 5 shows corresponding improvements to CD STFI Index of 3 to 20%, and improvements to GM STFI Index of between 0.7 and 17%. These gains of impulse drying over wet pressing are also summarized in Figure 6. Clearly, impulse drying was beneficial.

CONCLUSIONS

The pilot paper-machine experiments confirmed that the ramp decompression concept can be used to increase critical impulse drying temperature, thus opening the operating window of the technology. The adjustable shoe was found to work well, while the "hover press," in its present form, was found to have increased rewet and to have negatively impacted paper properties.

A combination of the specially designed press roll surface and the TET doctor helped to minimized picking. Venting of the nip and blanket groove geometry were found to be important variables that should, in future work, be optimized.

In general, improvements were found to be greatest at higher freeness, higher ingoing solids, and for longer nip residence times.

FUTURE RESEARCH GOALS

In the near future, additional experiments will be conducted on the Beloit X2 pilot paper machine at higher basis weights and higher ingoing solids in an attempt to match those required to produce 126 gsm linerboard and to simulate the impulse dryer operating at typical ingoing solids of a third press. These experiments will seek to optimize press shoe pressure profile, blanket groove geometry, felt, and post-nip decompression.

Once these results are obtained, experiments will be run on the Beloit X4 pilot paper machine at a basis weight of 205 gsm and at an ingoing solids typical of current third press applications. The objective of these experiments will be to set up the machine for a long demonstration run.

The last step will be to demonstrate impulse drying of 205 gsm linerboard on the Beloit X4 pilot paper machine, producing a sufficient number of rolls of paper for converting trials.

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TABLES

Table 1. Comparison of Operating Conditions in Summer 1997 and Winter 1998

Section of P.M.	Operating Condition	Summer 1997	Winter 1998
Forming	#1 Wire	145 x 104	152 x 68/34
	#2 Wire	182 x 145	161 x 110
	Pressure	36 kPa	32 kPa
	Flowrate	3226 l/min	2271 l/min
	Thick Stock	560 l/min	530 l/min
	Temperature	47°C	43°C
	pH	7.7	NA
Pressing	Solids In	32%	25%
	Press Shoe	0.15 m with ramp extension	0.25 m with adjustable ramp
	"Hover Press"	none	installed-variable pressure
	Felt	AI 289250 CSX	AI 289249 CSX
	Wrap Roll	inside link	outside link
	Blanket	grooved	op. side- blind drilled/ dr. side- grooved

Table 2. Ingoing Web Properties

Case Date - Ramp # P.M. Speed	Freeness, ml CSF	Ingoing Solids, %	Specific Surface, m^2/g Average Std. Dev.	Specific Volume, g/m^3 Average Std. Dev.	OD Basis Weight, g/m^2 Average Std. Dev.
Summer- Ramp 4 380 m/min	570	32.2	3.20 0.03	1.16 0.02	105.5 6.8
Summer- Ramp 5 380 m/min	570	31.5	4.07 0.87	1.10 0.03	105.5 6.8
Winter - Ramp 8 380 m/min	540	24.6	6.60 1.43	1.84 0.09	98.5 4.9
Winter - Ramp 8 380 m/min	458	27.5	11.16 1.28	1.75 0.09	97.6 2.9
Winter - Ramp 8 760 m/min	460	26.1	14.97 1.71	1.77 0.01	97.9 2.6

<u>Table 3.</u> Critical Impulse Drying Temperatures

Case Date, Freeness, P.M. Speed	Specific Surface, m^2/g	Ingoing Solids, %	Press Shoe Configuration	Critical Impulse Drying Temperature, °C	
				Blind Drilled	Grooved
Summer 570 ml CSF 380 m/min	na	30.0	Std - No Ramp	na	164
Summer 570 ml CSF 380 m/min	3.20	32.2	Short -Ramp 4	na	218
	4.07	31.5	Short -Ramp 5	na	209
Winter 540 ml CSF 380 m/min	6.63	24.6	Std - Ramp 8 Off -Hover Off	188	203
			Std - Ramp 8 On -Hover Off	216	216
			Std - Ramp 8 On -Hover On	217	217
Winter 458 ml CSF 380 m/min	11.16	27.5	Std - Ramp 8 Off -Hover Off	200	200
			Std - Ramp 8 On -Hover Off	232	232
			Std - Ramp 8 On -Hover On	243	243
Winter 460 ml CSF 760 m/min	14.97	26.1	Std - Ramp 8 Off -Hover Off	216	216
			Std - Ramp 8 On -Hover Off	228	228

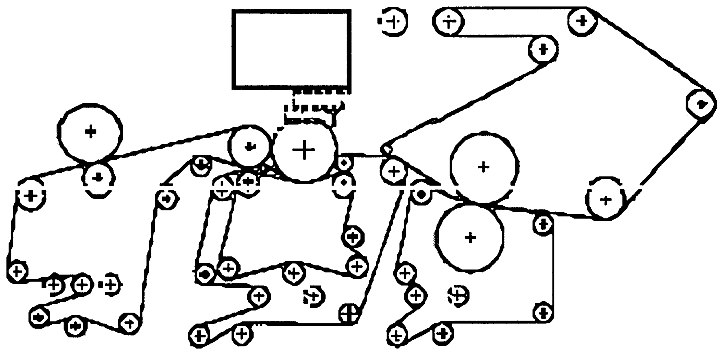
Table 4. Outgoing Solids and Bendtsen Roughness: Improvement of Impulse Drying Compared to Wet Pressing with a Standard 0.25-m Press Shoe.

Case Date, Freeness, P.M. Speed	Press Shoe Configuration	Outgoing Solids, %			TS-Bendtsen Roughness, ml/min		
		W P	I D	% incr.	W P	I D	% decr.
Summer 570 ml CSF 380 m/min	Std - No Ramp	43.4	43.5	+0.2	1135	632	+44.3
Summer 570 ml CSF 380 m/min	Short -Ramp 4	44.0	48.1	+10.8	1140	550	+51.5
	Short -Ramp 5	44.2	47.8	+10.1	870	620	+45.4
Winter 540 ml CSF 380 m/min	Std - Ramp 8 Off -Hover Off	42.8	45.2	+5.6	1740	1340	+23.0
	Std - Ramp 8 On -Hover Off	na	44.7	+4.4	na	1250	+28.2
	Std - Ramp 8 On -Hover On	na	41.7	-2.6	na	1330	+23.6
Winter 458 ml CSF 380 m/min	Std - Ramp 8 Off -Hover Off	40.2	43.8	+9.0	1780	1780	+00.0
	Std - Ramp 8 On -Hover Off	40.7	45.6	+13.4	1600	1000	+43.8
	Std - Ramp 8 On -Hover On	39.5	44.2	+10.0	1580	990	+44.4
Winter 460 ml CSF 760 m/min	Std - Ramp 8 Off -Hover Off	37.9	40.9	+7.9	1770	1370	+22.6
	Std - Ramp 8 On -Hover Off	38.1	40.9	+7.9	1600	1380	+22.0

Table 5. CD and GM STFI Compression Strength Indices: Improvement of Impulse Drying Compared to Wet Pressing with a Standard 0.25-m Press Shoe.

Case Date, Freeness, P.M. Speed	Press Shoe Configuration	CD STFI Index, Nm/g			GM STFI Index, Nm/g		
		W P	I D	% incr.	W P	I D	% incr.
Summer 570 ml CSF 380 m/min	Std - No Ramp	19.7	22.8	+15.7	25.6	28.2	+10.2
Summer 570 ml CSF 380 m/min	Short -Ramp 4	19.9	23.4	+18.8	26.1	30.1	+17.6
	Short -Ramp 5	22.7	23.7	+20.3	28.0	28.9	+12.9
Winter 540 ml CSF 380 m/min	Std - Ramp 8 Off -Hover Off	21.2	21.0	-0.9	27.0	26.9	-0.4
	Std - Ramp 8 On -Hover Off	na	22.8	+7.5	na	27.4	+1.5
	Std - Ramp 8 On -Hover On	na	21.1	-0.5	na	26.2	-3.0
Winter 458 ml CSF 380 m/min	Std - Ramp 8 Off -Hover Off	23.4	22.1	-5.6	30.6	29.7	-2.9
	Std - Ramp 8 On -Hover Off	23.0	24.2	+3.4	30.4	30.8	+0.7
	Std - Ramp 8 On -Hover On	24.5	22.2	-5.1	31.4	30.1	-1.6
Winter 460 ml CSF 760 m/min	Std - Ramp 8 Off -Hover Off	21.1	21.8	+3.3	28.8	29.1	+1.0
	Std - Ramp 8 On -Hover Off	20.1	22.0	+4.3	28.2	29.8	+3.5

ILLUSTRATIONS



Schematic Diagram Of Beloit X2 Pilot Paper Machine

Figure 1. Beloit X2 pilot paper machine.

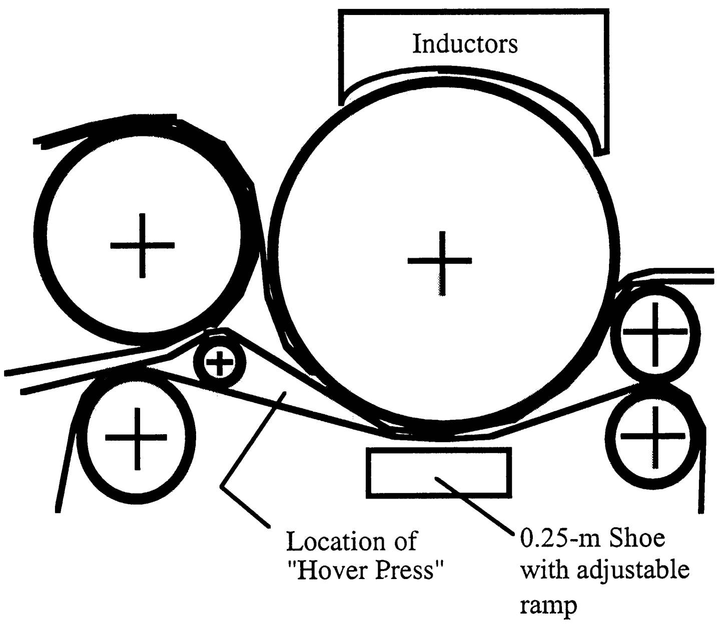


Figure 2. Close-up of the Winter 1998 configuration of the impulse dryer on the Beloit X2 pilot paper machine.

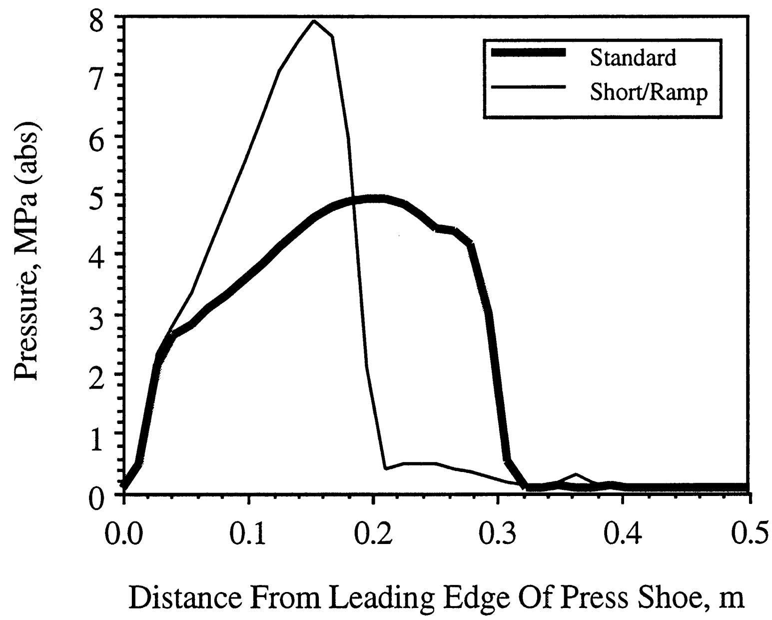


Figure 3. Measured pressure profiles of the standard 0.25-m-long and "short" shoe used in the Summer 1997 experiments on the Beloit X2 pilot paper machine.

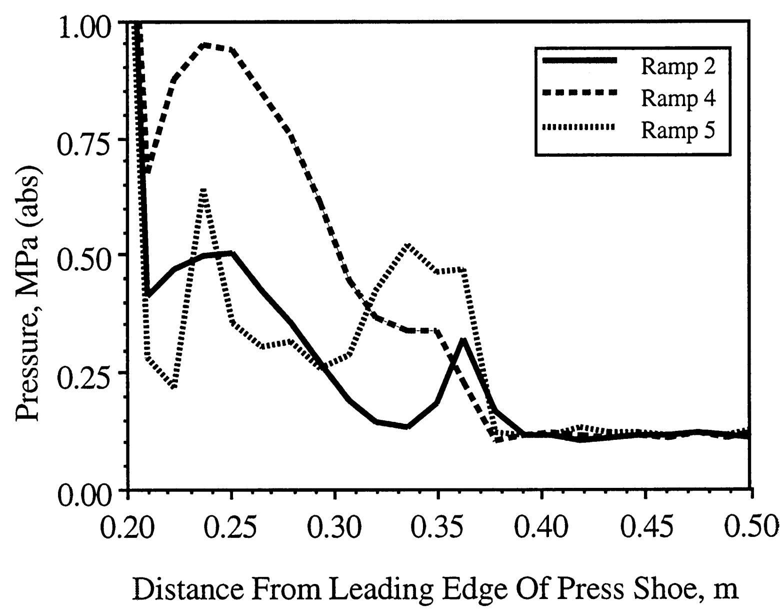


Figure 4. Measured pressure profiles of various ramp decompression profiles used in the Summer 1997 experiments on the Beloit X2 pilot paper machine.

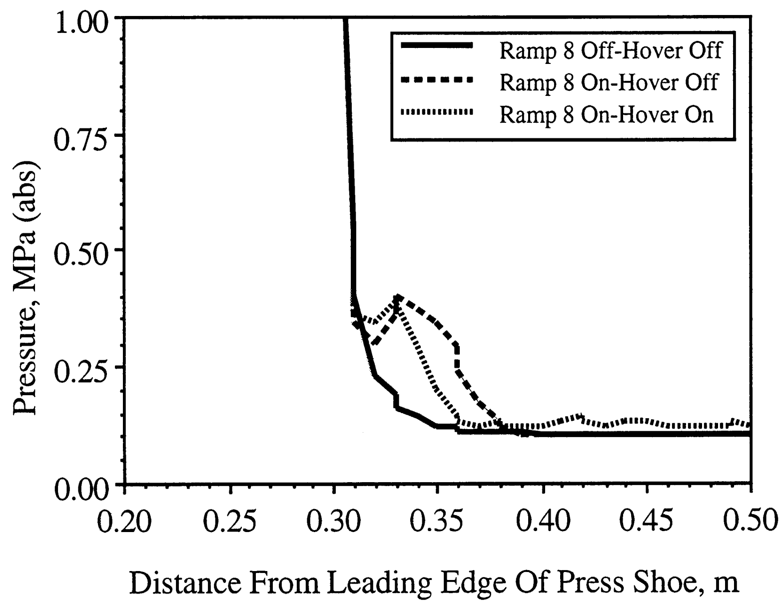


Figure 5. Measured pressure profiles of various ramp decompression profiles used in the Winter 1998 experiments on the Beloit X2 pilot paper machine.

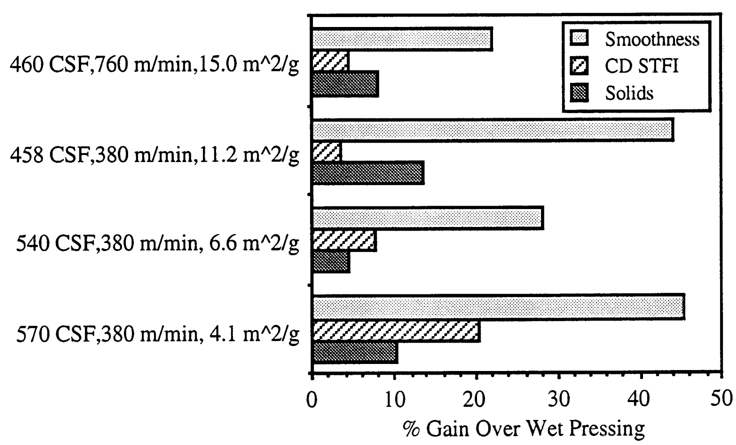


Figure 6. Percentage gain in press dryness, CD STFI compression strength and smoothness of impulse drying as compared to wet pressing at the same press impulse.